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(54) **SOx Trap for Diesel and Lean-Burn Gasoline Automotive Applications**

(57) The present invention relates to a regenerable catalyst composition suitable for entrapping SO_x, a Diesel oxidation catalyst (DOC) or a catalyzed soot filter (CSF) comprising said catalyst composition. The invention furthermore relates to the use of said catalyst composition for adsorbing SO_x as metal sulfate under lean conditions and desorbing accumulated SO_x as SO_2 under rich conditions. Such reversible SO_x trap material is able to work under typical NO_x trap operating conditions to prevent sulfur poisoning of NO_x trap and can be regenerated under rich conditions of NO_x trap operation at 300-450°C.

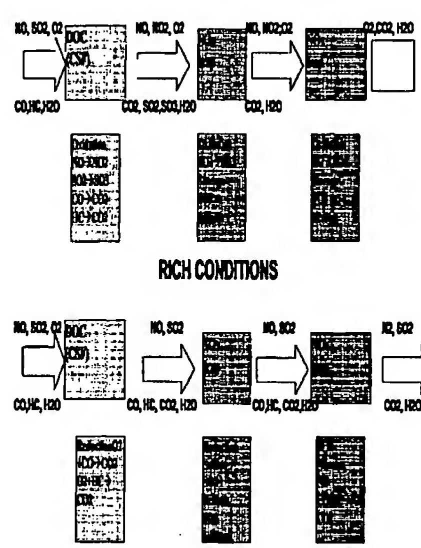
The platinum group metal free (PGM-free) regenerable catalyst composition substrate is suitable for entrapping SO_x having the general structure

Cu/ A oxide

whereby
A oxide represents SiO_2, Zr-SiO_2, Al_2O_3, TiO_2-Al_2O_3, ZrO_2 and In_2O_3 and mixtures thereof.

For irreversible SO_x trap, which can collect SO_x under lean conditions and can be regenerated only at elevated temperatures in a separate mode of operation, the systems containing praseodymia, zirconia-praseodymia and mixed manganese-yttria and mixtures thereof have shown to be an effective material for SO_x removal.

Fig.1. LEAN CONDITIONS



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Description

[0001] The present invention relates to a regenerable catalyst composition suitable for entrapping SO_X, and a Diesel oxidation catalyst (DOC) or a catalyzed soot filter (CSF) comprising said catalyst composition. The invention furthermore relates to the use of said catalyst composition substrate for adsorbing SO_x as metal sulfate under lean (oxidative) conditions and desorbing accumulated sulfate as SO_2 under rich (reducing) conditions. This composition, further called as SO_X trap, is designed to prevent sulfur poisoning of aftertreatment devices, especially NO_X trap or NO_X reduction catalyst and SO_X trap mentioned works under typical operating conditions of NO_X trap.

[0002] The invention in particular relates to an automotive aftertreatment system for elimination of exhaust gas emissions, basically for Diesel, Lean-Burn and Natural Gas fueling vehicles. The invention also relates to removal of SO_x from stationary operating engines and in industry and power generation plants.

[0003] Sulfur oxides (SO_x) have a negative effect on a performance of components of automotive catalysts and traps, such as noble metals, Ce-Zr oxide etc [T. J. Truex "Interaction of Sulfur with Automotive Catalysts and the Impact on Vehicle Emissions-A Review", SAE Technical Paper Services, 1999-01-1543, 1999, and referenced therein]. At present, one of the most challenging problems for Lean Burn gasoline and especially Diesel engines, having higher fuel efficiency, is removal of NO_x toxic components. There is a lack of reductants for selective catalytic reduction of NO_x to nitrogen for such kind of engines. The current 3-way catalysts cannot meet the requirements of newly developed engines with lean air/fuel region. The most promising way to solve this problem is NO_x trap (NO_x storage catalyst), having the ability to store NO_x under oxidizing (lean) conditions and to reduce the stored NO_x to N_2 under reducing (rich) conditions. This kind of system has been applied to lean-burn gasoline engines in Japan [K. Yamazaki, T. Suzuki, N. Takahashi, K. Yokota, M. Sugiura; Applied Catalysis B: 30 (2001) 459-468]. Toyota Motor Co announced the application of NO_x trap containing system for Diesel engine vehicles starting in 2003 [J. L. Broge. Automotive Engineering International, October 2000, p. 119]. Unfortunately, the strong drawback of NO_X trap is its intolerance to SO_X compounds derived from sulfur in the fuel and lube oil, leading to gradual deterioration of its performance. While SO_2 is adsorbing relatively weak, sulfur dioxide can be easily oxidized to SO_3 on Pt catalyst. The last compound reacts with barium and/or other alkaline or alkaline-earth metal components of NO_x trap, forming stable sulfates [S. Hodjati, P. Bernhardt, C. Petit, V. Pitchon, A. Kiennenmann "Removal of NO_x: Part I. Sorption/desorption processes on barium aluminate", Applied Catalysis B. Environmental 19 (1998) 209-219]. Thermodynamically any metal sulfate is more stable than corresponding metal nitrate and decomposes at higher temperatures, thus there is a little chance to create any NO_x trap having sulfur resistance, despite of numerous attempts. This problem is especially hard for Diesel engines due to the higher sulfur level in fuel in comparison with gasoline engines. Hence this technique can be used only for limited markets such as Japan where the sulfur content in gasoline and Diesel fuel is very low, but periodical desulfation of NO_x trap is also required. The current strategy of periodical desulfation is to increase the temperature up to 600°-650°C under rich conditions. [U. Göbel, T. Kreuzer, E. Lox VDA Technical Congress, 1999, p. 319-332, S. Erkfeld, M. Larsson, H. Heldblom and M. Skoglundh, SAE 1999-01-3504], which is complex, requires high fuel penalty and special control management strategy and in addition leads to gradual thermal deactivation of NO_X trap.

[0004] One of the possible solutions to avoid sulfur poisoning of the NO_X trap or $DeNO_x$ catalyst is to place the SO_X storage material upstream of NO_X trap [S. Detterbeck; P. Mueller and M. Preis, Ger. Offen. DE 19,753,573 (Cl. F01N3/20), 10 June 1999, Appl. 03. Dec. 1997; T Nakatsuiji, R. Yasukawa, K. Tabata, K. Ueda and M. Niwa. Chem. Lett. 1998, (10), 1029]. According to operation conditions of the NO_x traps, SO_x storing material should be able to collect SO_2 under lean conditions in the temperature window of the NO_x trap (normally 300 - 450°C [J. S. Hepburn, E. T. Thanasiu, D. A. Dobson, W. L Watkins, "Experimental and Modeling Investigations on NO_X Trap Performance", SAE Technical Paper Series. 962051, 1996]), and to be regenerated under conditions that are safe for the NO_x trapping material. Under rich (reducing conditions) SO_2 is not expected to be a poison for the NO_x trap [M.A. Dearth, J.S. Hepburn, E. Thanasiu, J. McKenzie, G. Scott Horne "Sulfur interaction with lean NO_x Traps: Laboratory and Engine dynamometer studies", SAE Technical Paper Series, 982592 1998 9 pp.; P. Engstrom, A. Amberntsson, M. Skoglundh, E. Fridell, G. Smedler "Sulphur dioxide interaction with NO_x storage catalyst", App. Catal. B., 22 (1999) L241-L248; O. H., D. Dou and M. Moliner, SAE 2000-01-1205], taking into account also the elevated temperatures during rich excursions which are favorable for SO_2 desorption and further that NO_x trap is full of adsorbed NO_x at the moment of SO_2 release, that prevents SO_2 adsorption on NO_x trap material.

[0005] Copper, iron, and manganese containing systems were, historically, the first materials proposed for reversible SO_x removal from flue- and other industrial waste gases. Early studies [R. F. Vogel, B. R. Mitchell, F. E. Massoth "Reactivity of SO_2 with supported metal oxide-alumina sorbents", Environ. Sci. Technol., 8, No. 5 (1974) 432-436; M. H. Cho, W. K. Lee "SO_2 removal by CuO on γ-alumina", J. Chem. Eng. Japan, 16, No. 2 (1983)127-131; J. H. A. Kiel, W. Prins, W. P. M. van Swaaij "Flue gas desulfurization in a gas-solid trickle flow reactor with a regenerable sorbent", in: Gas Separation Technology (ed. E. F. Vansant, R. Dewolfs), Elsevier, Amsterdam, 1991, 539-548] have shown that copper oxide-based sorbents (typically, 5% Cu on a support) have the best sorption-regeneration characteristics for applications at around 350-400 °C. Copper containing systems displayed reasonable stability in multi-cycle processes,

including tolerance to water vapors and over-heating. Those systems are still in use for high-temperature SO_x removal from flue gases, basically Cu/Al_2O_3 and more recently $Cu-CeO_2$ [Yoo K. etc. Ind. Eng. Chem. Res., v. 33, 7 (1994), p. 1786, J. F. Akyurtlu, A. Akyurtlu, Chem. Eng. Sci., 54 (15-16) 2191-2197 (1999), H. W. Pennline, Fuel & Energy Abstracts, 38 (1997), N3, p. 187, Centi G., Perothoner S., Developments in Chem. Eng. & Mineral Processing, 8 (2000), N5-6, p. 441, Wang Z. Industrial & Eng. Chem. Research, 37 (1998), N12, p. 4675, Jeong S., Kim S., Industrial and Eng. Chem. Research, 39 (200), N6, p. 1911].

[0006] Recently, a number of other materials were proposed and studied for that purpose, including $Pt-CeO_2-ZrO_2$ and $Pt-CeO_2$ [F. M. Allen, S. Khairulin, T. J. Zega, R. J. Farrauto "Reusable SO_x traps: Materials and methods for regeneration", AIChE Meeting, Nov. 15-20, 1998, Miami, FL; Section 4-3, p. 84-5], $MgAl_{2-x}Fe_xO_4$ [J. Wang, Z. Zhu, C. Li "Pathway of the cycle between the oxidative adsorption of SO_2 and the reductive decomposition of sulfate on the $MgAl_{2-x}Fe_xO_4$ catalyst", J. Mol. Catal., 139 (1999) 31-41], $MgAl_2O_4$ [M. Waqif, O. Saur, J. C. Lavalley, Y. Wang, B. Morrow "Evaluation of magnesium aluminate spinel as a sulfur dioxide transfer catalyst", Appl. Catal., 71 (1991) 319-331], Co-Mg-Al mixed oxides [A. E. Palomares, J. M. Lopez-Nieto, F. J. Lazaro, A. Lopez, A. Corma "Reactivity in the removal of SO_2 and NO_x on Co/Mg/Al mixed oxides derived from hydrotalcites", Appl. Catal. B., 20 (1999) 257-266], $Cu-CeO_2$ [3. F. Akyurtlu, A. Akyurtlu, Chem. Eng. Sci., 54 (15-16) 2191-2197 (1999)].

[0007] Dual-functional systems containing components for oxidizing SO_2 to SO_3, namely Pt, and SO_x- storing components selected from Ti, Zr, Sn, Fe, Ni, Ag and Zn oxides are described [K. Okuide, O. Kuroda, T. Yamashita, R. Doi, T. Ogawa, M. Fujitani, H. Lizuka, Sh. Azukibata, Yu. Kitahara and N. Shinotsuka. Jpn. Kokai Tokyo Koho JP 11 169, 708 [99 169,708] (Cl. B01J23/42), 29 June 1999, Appl. 1997/344,682, 15 Dec. 1997]. These systems operate in two periodic steps, consisting of an operation under oxidizing conditions and a far shorter operation under reducing conditions.

[0008] The references are recent and not numerous on applications of SO_x traps and SO_x sorbents for automotive aftertreatment.

[0009] Authors from Engelhard [F. M. Allen, S. Khairulin, T. J. Zega, R. J. Farrauto "Reusable SO_x traps: Materials and methods for regeneration", AIChE Meeting, Nov. 15-20, 1998, Miami, FL; Section 4-3, p. 84-5] mentioned the possible use of $Pt-CeO_2-ZrO_2$ and $Pt-CeO_2$ for mobile applications. Degussa [Automotive Engineering/February 1997, p. 133] tried to use Pd-Ba sulfur traps, but with only partial success. ASEG Manufacturing [O. H. Bailey, D. Dou and M. Moliner, Sulfur traps for NO_x adsorbers, SAE 2000-01-1205] tested different sulfur traps without any indication of composition. Sakai Chemical [T. Nakatsuji, R. Yasukawa, K. Tabata etc. Highly durable NO_x reduction system. SAE 980932] claimed Ag/Al_2O_3 as effective SO_x trap material. Goal Line [SAE 2000-01-1012, 2000-01-1932, 1999-01-2890, 1999-01-3557] issued 4 publications on sulfur sorbate materials and traps without indication of their compositions, except it contains Pt.

[0010] US-Patent 5,472,673 relates to SO_x adsorbents selected from alkali, alkali-earth, rare earth metals, in addition containing Pt. Those compositions cannot be regenerated under NO_x trap temperature limits, so it requires the separate mode of operation under high temperatures; these materials can work as only irreversible SO_x traps. Any Pt containing adsorbents are also not acceptable due to the H_2S release under rich conditions, as one can see below.

[0011] US-Patent 5,473,890 refers to SO_x absorbent containing at least one member selected from copper, iron, manganese, nickel, sodium, tin, titanium, lithium and titania. In addition Pt is used for SO_x adsorbent. Authors did not show any example of the performance of such absorbents. The carrier is made of alumina. In this case, it is clarified that the adsorbent carrying lithium Li on the carrier made of alumina is most preferred.

[0012] US-Patent 5,687,565 claims a very complex oxide composition; designed for gasoline applications with high temperature of regeneration of SO_x trap material and not designed to prevent the poisoning of NO_x trap, so it can be related to irreversible trap material. Any their composition contains alkaline-earth oxides (Mg, Ca, Sr, Ba) or Zn. The mentioned Cu only can promote the basic formulations. In addition, they used a small amount of noble metals (Ru, Os, Pd, Pt etc.).

[0013] US-Patent 5,792,436 applies the sorbents containing alkaline earth metal oxides of Mg, Ca, Sr, Ba in combination with oxides of cerium, Pr and group of oxides of elements of atomic numbers from 22 to 29 inclusive. Pt is in service for all adsorbents. Cu and Pr is mentioned without any real examples and only in combination with other elements, for example Pt. The regeneration temperatures for SO_x removal are high.

[0014] Those prior art systems were developed basically for the removal of SO_x from stationary systems and industry, while the reversible SO_x storage for vehicles and especially for NO_x traps demands the new special requirements for SO_x trap development and another solutions in comparison with SO_x removal in industrial applications.

[0015] For the development of SO_x trap first it is necessary to evaluate the basic requirements to SO_x trap to operate, see Figure 1.

[0016] For successful application the SO_x trap has to do the following:

- To prevent the poisoning of NO_x trap by complete removal of SO_x upstream of NO_x trap accumulating SO_x as sulfates on the surface of storage material at wide temperature range under lean conditions.
- To decrease the temperature of desulfation to NO_x temperature operating limits under rich conditions.
- To eliminate the thermal deactivation of NO_x trap due to the low temperature of desulfation.

- To synchronize the desulfation and NO_x reduction events under rich conditions, that leads to more simple control management.
- To allow the NO_x trap to operate with constant activity in continuous mode without gradual decrease of activity between desulfation steps.
- To use the higher sulfur level fuel.
- To prevent the formation of sulfated ash.

  Based on that, the following main criteria have been taken into account to evaluate the materials as candidates for SO_x storage material:
- High adsorption rate and SO_x adsorption capacity at wide temperature range (200-500°C) under lean conditions.
- Thermal stability of sulfates accumulated up to 600°C under lean conditions.
- Complete removal of SO_x at wide temperature range under lean conditions.
- High activity of SO_2 oxidation to SO_3 is desirable. If oxidation catalyst (DOC) or catalyzed soot filter (CSF) capable to oxidize SO_2 to SO_3 is installed upstream of SO_x trap, such requirement is not mandatory.
- The lower temperature of SO_2 release as possible under rich conditions.
- The narrow temperature range of SO_2 release under rich conditions.
- The only SO_2 release under rich conditions to prevent H_2S slip above the smell threshold level.
- Low cost, convenient method of preparation, opportunity to deposit on monolith, and good thermal stability.

[0017] For material selection, the following considerations have been taken into account. It is well known that the only oxides of Si, B, and P having an acid nature, and some oxides like WO_3, MoO_3, Re_2O_7, where the metal is in high valence state, do not form sulfates at all on the surface, while other oxides having basic sites form sulfates on the surface. Among them, the oxides that contain an alkali or alkaline earth metals are able to desorb sulfates only at extremely high temperatures above 1000 °C, and the sulfates tend to be desorbed only at 550-650 °C or higher even under reducing environment. Therefore such oxides would be impossible to use as regenerable SO_x traps. From other side, the oxides with a weak basic adsorption sites do not have a good affinity to SO_x compounds. From this point of view, the oxides containing moderate basic sites look most promising as a material for SO_x traps. Although silica does not form sulfates, it may be used as a support taking into account the high surface area of silica and silica probably may decrease the temperature of SO_x desorption. The same considerations can be applied for alumina and titania, having relatively weak basic properties, for its use as supports for more active SO_x capturing material. The transition metal oxides have a low surface area and should be deposited on support for their application in adsorption. So we decided to study the SO_x adsorption-desorption properties of the wide group of oxides having different basicity including some binary and ternary systems to evaluate them as candidates for SO_x traps. In addition we studied the effect of Pt, known as most effective catalyst for oxidation SO_2 to SO_3 [T. R. Felthouse, D. A. Berkel, S. R. Jost, E. L. McGrew, A. Vavere Platinum-Catalyzed Sulfur Dioxide Oxidation Revisited, in: Advanced Catalysts and Nanostructured Materials - Modern Synthetic Methods, (W. R. Moser Ed.), Academic Press, San Diego-London-Boston-New York-Sydney-Tokyo-Toronto, 1996, p. 91-115], and for reduction of SO_x species in hydrogen [P. Bazin, O. Saur, J. C. Lavalley, G. Blanchard, V. Visciglio, O. Touret "Influence of platinum on ceria sulfation", Appl. Catal. B. 13 (1997), 265-274], on performance of trap materials studied. Cu and Fe containing zeolites, known as active SCR catalysts, were also tested.

[0018] The present invention is devoted to the development of regenerable SO_x trap for Diesel and lean-burn gasoline automotive applications. That SO_x trap will be designed to prevent the sulfur poisoning of automotive catalysts and especially NO_x traps, while installed upstream of those devices. The SO_x trap should remove and accumulate sulfur compounds on its surface at wide temperature range under lean conditions, thus preventing the sulfur poisoning, while it should easy release sulfur compounds as SO_2 at low temperatures as possible under short periods of rich (reducing) conditions. The noble metal components of NO_x trap cannot oxidize under rich conditions and cannot accumulate sulfur as metal sulfates, while SO_2 is weakly adsorbed, especially at elevated temperatures and easy removes under rich conditions. It should facilitate the automotive catalysts and NO_x traps to operate in continuous mode at lower temperatures using high-level sulfur containing fuels. The trap should allow synchronizing the desulfation and NO_x reduction events under rich conditions. To develop this idea, the different materials have been tested as promising candidates for SO_x trap materials. Among them, the copper-containing materials, especially Cu/SiO_2, $Cu/ZrSiO_2$, Cu/Al_2O_3, $Cu/TiO_2.Al_2O_3/Cu/ZrO_2$, Cu/In_2O_3 were found to fit the basic requirements for SO_x reversible trap materials. These materials have a high adsorption capacity and good rate of SO_x adsorption as sulfates at wide temperature range (200-500°C) under lean conditions, while release accumulated sulfates as SO_2 at low temperatures (250-450°C) with narrow temperature range of complete removal of sulfates in the course of desulfation event.

[0019] For irreversible SO_x trap, which can collect SO_x under lean conditions and can be regenerated only at elevated temperatures in a separate mode of operation, the systems containing praseodymia, zirconia-praseodymia and mixed Mn-yttria were found to be an appropriate material.

[0020] Such SO_x trap could be installed upstream of NO_x trap and preferably downstream of Diesel oxidation catalyst (DOC) or catalyzed soot filter (CSF) to provide high effectiveness of SO_x removal. The other possible positioning of SO_x

trap includes impregnating of DOC and/or CSF with SO_x trap material, or SO_x trap material can be applied to CSF together with NO_x trap material.

[0021] A first embodiment of the present invention is directed to a platinum group metal free (PGM) regenerable catalyst composition substrate suitable for entrapping SO_x having the general structure

Cu/ A oxide

whereby

a oxide represents SiO_2, Zr-SiO_2, Al_2O_3, TiO_2-Al_2O_3, ZrO_2 and In_2O_3 and mixtures thereof.

[0022] Said catalyst may in particular be used for adsorbing SO_x as metal sulfate at a temperature in the range of 200 to 500 °C under lean (oxidizing) conditions. The desorption of said metal sulfate from the surface of the catalyst may be arranged at a temperature in the range of 250 to 450 °C under rich (reducing) conditions.

[0023] A second embodiment of the present invention is directed to a platinum group metal free (PGM) regenerable catalyst composition substrate suitable for entrapping SO_x containing praseodymia, zirconia-praseodymia and mixed manganese-yttria and mixtures thereof.

[0024] Said catalyst composition substrate may in particular be used for adsorbing SO_x as metal sulfate at a temperature in the range of 200 to 500 °C under lean (oxidizing) conditions. The desorption of the metal sulfate from the surface of the catalyst composition may be arranged at a temperature in the range of 600 to 650°C under rich (reducing) conditions.

[0025] The above referenced catalyst composition may be applied as a part of Diesel oxidation catalyst (DOC) or catalyzed soot filter (CSF). Generally, said catalyst composition substrate should be installed upstream of a IMO_x trap, in particular downstream of said DOC or CSF respectively.

Examples:

Materials

[0026] A commercial silica gel purchased from Aldrich® (Silica gel for column Chromatography 70-230 mesh, pores of 60 Å) and calcined at 800 °C for 2h was used for all experiments.

[0027] SiO_2-supported sorbents were prepared by impregnation of silica gel with corresponding metal nitrates (supplied by Aldrich® and Alfa® Aesar), with following drying and calcination at 620°C for 2h.

[0028] Zr-SiO_2 support was prepared by impregnation of SiO_2 with Zr citrate, ammonium complex (Aldrich®) followed by drying and calcinations for 2h at 800°C with zirconium content of 10wt% of ZrO_2.

[0029] Zr-SiO_2-supported sorbents were prepared by the same procedure as for SiO_2-supported materials.

[0030] Pt on Zr-SiO_2 was prepared by impregnation of support with water solution, containing H_2PtCl_6 and citric acid, followed by drying and calcinations for 2h at 600°C. Platinum loading was maintained constant as 1 wt%.

[0031] For all materials prepared on silica, the original 70-230 mesh size samples were used for TG experiments and TPR-MS runs.

[0032] ZrO_2, CeO_2, Pr_6O_{11}, and double oxides CeZr 1:1 (molar ratio), CePr 1:1, ZrPr 1:1, Cu and Ag-containing binary systems with ceria, zirconia, india, magnesia, zinc, yttria and copper oxide, Mn-yttria were prepared by cellulose templating method, using Whatman® 542 filter paper as cellulose material. The detailed procedure is described elsewhere [A. N. Shigapov, G. W. Graham, R. W. McCabe, US Patent 6,139,814, Oct. 31, 2000]. Briefly, a cellulose material was impregnated with 0.1-0.2 M solution of precursor nitrate salts (zirconium dinitrate oxide in case of zirconia) in water with the following drying at room temperature overnight and combustion of cellulose material at 800 °C for 2h.

[0033] Pt-loaded Zr, Ce, and Pr single and binary oxides were prepared by the same procedure described above for Pt- (Zr-SiO_2) system. Pt loading was equal to 1 wt% for all systems tested, except Pt-CeZr and Pt-CePr (2 wt% Pt).

[0034] All samples were used for TGA experiments as obtained.

[0035] Alumina-titania mixed supports, alumina, and titania were prepared by modified sol-gel method including fast hydrolysis in excess of boiling water of metal alkoxides followed by drying and calcination [C. N Montreuil and M. Chattha, US Patent 5,922,294]. Samples were calcined at 600°C and at 800°C.

[0036] 1 wt % Pt on Al-Ti, Al_2O_3 and TiO_2 samples were prepared from a corresponding Al-Ti sample by impregnation of a support with H_2PtCl_6 solution followed by calcination, and Pt reduction in 5%H_2-N_2 for 3h at 400°C.

[0037] The sample Ti-Al (8:1) was prepared by the modified sol-gel method using impregnation of filter paper with alcohol solution of metal alkoxides followed by drying and calcinations at 600°C or 800°C. The support thus obtained was impregnated with the solution of copper nitrate. Cu/alumina samples were prepared by impregnation of commercial γ-alumina, Brockmann acidic S=155 m^2/g, with copper nitrate with the following drying and calcinations at 600°C.

[0038] FeZSM5-30 sample was prepared from 80-wt% of HZSM-5 (SiO_2: Al_2O_3 = 30 (mol)) (Zeolyst Co.) and 20-wt% of a binder (Al_2O_3 sol). The material was then ion exchanged with Fe to an atomic ratio Fe/Al = 1.0. Calculated Fe content was 0.78 mmol Fe/g of a sample. Particles of 35-60-mesh size were used in the TG experiments.

[0039] FeZSM5-50, CuZSM5 and CuMgZSM5 zeolite samples. The detailed procedure is described elsewhere [A.V. Kucherov, A. N. Shigapov, A. A. Ivanov and M. Shelef. J. Catal., 186, 334-344 (1999)]. Iron or copper concentration was of 0.5 wt% Fe or Cu in ZSM-5 type zeolite (SiO_2: Al_2O_3 = 50). Zeolite sample was pressed into pellets, calcined for 2 h at 540°C followed by crushing and sieving. CuMgZSM5 had Cu concentration of 0.5 wt% and Mg concentration of 0.7 wt%.

[0040] Particles of 100/120-mesh size were used in the TG experiments except for CuZSM5 having particles less then 0.5 mm.

[0041] The BET surface area of samples studied is presented in Table 2 and 3.

[0042] Samples loading of 20-60 mg were typically used for the TG measurements.

Methods

Surface area and porosity

[0043] Texture properties of samples were studied by nitrogen adsorption-desorption at -196 °C using a Micromeritics ASAP 2400 instrument. The samples were outgassed at 350 °C for 2h prior to measurements.

XRD analysis

[0044] XRD measurements of materials tested were carried out using a Scintag® X1 diffractometer with Cu Kα radiation on powdered samples packed into a 1 mm-deep cavity in a zero-background quartz sample holder.

Thermogravimetric (TG) experiments

[0045] Experiments were performed using a setup based on the Cahn® 2000 microbalance operating in a flow mode. Helium UHP (100 sccm) was used to purge the microbalance chamber.

[0046] A conventional flow setup was used for gas mixtures preparation. All gases were of ultra high purity or certified calibration mixtures. Nitrogen and oxygen were additionally purified using standard columns with molecular sieves. Matheson® MF controllers were used to maintain the flow rates.

[0047] Quartz reaction vessel of tube-in-tube and side inlet/outlet design was used in the experiments performed with quartz suspensions and pans for the samples. The reaction gases (nitrogen, SO_2, hydrogen-argon mixture) entered the reaction vessel through the side inlet, heated by passing through the tube-in-tube zone, and directed upstream passing the sample. Far above the sample location, the reaction gas met with purge helium, and both gases exited the reaction vessel through the side outlet. Thermocouple was mounted in the special quartz tube inside the reaction vessel, positioned as close as possible to a sample pan. This temperature was assumed as a "sample temperature".

[0048] Standard sulfation gas of the following composition was used: 800 ppm SO_2, 10% O_2; nitrogen - balance. Flow rates of 50 to 150 sccm were used for different runs. Nitrogen UHP with flow rates of 50-150 sccm was used during isothermal desorption (purge) or TPD (50 sccm only) of the SO_x formed. Certified mixture of 1000 ppm SO_2 in nitrogen was used as SO_2 supply of the reaction gas. 10% H_2 in Ar mixture from a cylinder was used for the rich (reducing) experiments with flow rate of 50 sccm.

[0049] Tests included the following treatments:

1. Pretreatment in 10%O_2-N_2, flow 55 sccm; fast heating of the sample from room temperature to 200°C; then temperature-programmed heating (10°C/min) from 200 to 700°C; holding sample for 10 min at 700°C; cooling to 500°C.

2. 1hour-SO_x uptake tests at 500 °C using gas containing 800 ppm SO_2, 10%vol. O_2 in nitrogen (standard SO_x gas mixture) with flow rate of 50 sccm).

3. SO_x isothermal desorption test at 500 °C h was performed in nitrogen flow of 50 sccm for 0.5h after the sulfation.

4. TPD (SO_x thermal stability test) in the temperature interval of 500-700 °C with heating rate of 5 °C/min.

5. TPR (SO_x and extra-species reducibility test) in the temperature interval of 200-700 °C, with heating rate of 5 °C/min, and using 10% vol. H_2 in Ar (50 sccm) as the reducing agent.

6. 1hour-SO_x uptake tests at 200 °C using the standard SO_x gas mixture followed by:

7. Temperature-Programmed Sulfation (TPS) test (all in the standard SO_x gas mixture); temperature-programmed heating (1 °C/min) from 200 to 615 °C, holding 30 min at 615 °C, then cooling to 150-200 °C.

[0050] TG data were collected using the Rustrak® Ranger II Data Logger.

[0051] TPR-MS measurements of the sulfated samples.

[0052] The samples were sulfated overnight at 500 °C using the standard sulfation gas. Reduction of the materials was studied by temperature-programmed reduction (TPR) measurements carried out with an Altamira Instruments' AMI-1 system employing a thermal conductivity detector (TCD). The standard pretreatment of samples involved the heating of the powder sample (typical loading of 50 mg, although for some samples only 15 mg were available) at 500°C for one hour in a flowing mixture of 10% oxygen in helium at the rate of 25 cc/min. to ensure full oxidation. The sample was then cooled to 30°C in the same gas flow. The cooled sample is then purged with Ar prior to the introduction of reduction mixture. After switching to reduction gas (9.4 % H_2 in He) at flow rate of 25 cc/min, TPR experiment was attained by temperature ramp of the sample from 30°C to 900°C at the rate of 15°C/min and sampling the effluent gas from the AMI-1 into the Traspector-CIS_2 System mass spectrometer with electron multiplier (EM) from Leybold® Inficon Inc.

Results

Supports (Oxides of non-transition metals)

[0053] SO_x-related properties of a number of the single and binary oxides are presented in Table 1. Oxides are given in the order of increasing their basic properties (according to [Y. Moro-oka, Catal. Today, 45 (1998) 3-12]). There is an obvious trend of increasing SO_2 capture ability with the increase of the basicity of the material.

Table 1: Dependence of the SO_x trap properties of different oxides on their basicity. Basicity tends to increase downwards.

Oxide	SO_x loading at 200 °C, mg/g	SO_x loading at 500 °C, mg/g	SO_x loading at 500 °C, mg/m^2	Temperature of 50% thermal desorption, °C	Temperature of 50% reduction, °C
SiO_2	-	2.5	0.006	670	490
Zr-SiO_2	0.32	1.0	0.0025	635	470
TiO_2	2.3	3.0	0.12	>615	555
ZrO_2	6.3	8.8	0.14	>700	555
Al-Ti 1:8	2.4	2.2	0.047	683	500
Al-Ti 1:3	3.6	2.2	0.032	763	515
Al-Ti 1:1	5.0	1.7	0.018	791	540
Al-Ti 3:1	4.6	2.3	0.018	782	515
Al_2O_3	12.7	9.5	0.066	>800	580
CeZr 1:1	12	36	0.28	675	550
ZrPr 1:1	24	31	0.34	»700	660
CeO_2	3.1	30	0.28	695	590
CePr 1:1	3.6	39	0.42	»700	675
Y_2O_3	3.1	48	0.43	>700	605
Pr_6O_{11}	15	60	1.54	>700	675

[0054] The most basic oxides (downwards from Al_2O_3), as a rule, are very effective in SO_2 removal. Some of them (ZrPr and Pr_6O_{11}) are effective both at 200°C and 500°C. The less basic oxides (SiO_2, TiO_2, ZrO_2; Al_2O_3) exhibit lower SO_x capacities (per weight, and per specific area). At 200°C, only ZrPr and Pr_6O_{11} have SO_x capacity (per area) that is significantly higher than for the other materials. For practical application, the adsorption capacities per weight of the material are more important. In this respect, the oxides of Al_2O_3, CeZr, ZrPr, Y_2O_3 and especially Pr_6O_{11} are the most effective for SO_x removal. Analysis of the results obtained for binary (CeZr, ZrPr) oxides has shown that zirconium

addition increases the removal of SO_x at 200°C. For CeZr mixed oxide, the SO_x capacity of the binary oxide is higher than that of the individual oxides (CeO_2 and ZrO_2).

[0055] Thermal stability of the sulfates on all oxides studied is high enough; none of them is decomposed at temperatures lower than 615°C. The reduction characteristics of the sulfates are basically in the agreement with literature data reviewed in [A. Pieplu, O. Saur, J.-C. Lavalley "Claus Catalysis and H_2S selective oxidation", Catal. Rev.-Sci. Eng., 40 (4) 409-450 (1998)]. The temperature of reduction of sulfates increases with the increase of basic properties of the corresponding oxide. Sulfates formed on moderately basic oxides can be reduced and released at 470°C (Zr-SiO_2) - 550°C (zirconia, titania). The sulfates accumulated on more basic oxides can be regenerated only at 550 - 670°C. These temperatures are too high for automotive applications. The more basic oxides, such as La_2O_3, MgO have even higher temperatures of SO_x release upon reduction.

[0056] Obviously, there is no material, which is suitable as reversible SO_x trap. Rare earth-based oxides have too high temperature of SO_x reductive release (desulfation), while less basic oxides cannot capture SO_x from exhaust gases.

[0057] ***Pt-containing adsorbents*** The main properties of materials containing platinum are summarized in Table 2.

[0058] As a rule, Pt addition leads to increased SO_x capacity, especially at 200 °C, Pt is effective catalyst of SO_2 oxidation to SO_3 and accordingly, facilitates the sulfate formation on the material. From this point of view, the adsorption capacity at 200 °C is as a rule, lower than at 500 °C and reflects more the oxidative ability of material, than true adsorption capacity, while the most of materials studied are effective in SO_2 oxidation at 500 °C. As a rule, platinum addition lowers the temperature of the sulfation light-off (SLOT), the SLOT decrease was not observed only for Pr_6Oii, which is highly active itself at 200 °C and Cu-(Zr-SiO_2). For other systems, from 30 to 285 °C shift to lower temperature is observed. The reductive release of SO_x on Pt-containing systems is also usually shifted to lower temperature. Pt facilitates the reduction of sulfates and their removal from the surface of material. From these points of view, the Pt-containing systems look very attractive as SO_x trap, but the mass spectral analysis of the reductive regeneration products using the TPR-MS runs revealed the formation of H_2S as a main product. For the most active Pt-containing materials, Pt/CeO_2-ZrO_2, H_2S was the only product, see Figure 2. Pt promotes the deep reduction of the sulfates accumulated to H_2S. As an example, the fraction of H_2S was 21% on CeZr(1:1) mixed oxide, but the addition of Pt led to 100% selectivity to H_2S.

[0059] The fraction of H_2S was 35% for the best case, Pt/CeO_2. H_2S formation cannot be accepted for automotive applications, so the application of Pt-containing system as SO_x trap material faces the problem. Therefore, the better option is to use Pt in Diesel oxidation catalyst formulations upstream of SO_x trap to catalyze SO_2 oxidation to SO_3 under lean conditions, while non-platinum SO_x trapping material will capture SO_3 as sulfate. From this point of view, the better to use the supports for Diesel Oxidation Catalyst (DOC) with low SO_x capacity, e.g. Pt/TiO_2, see Table 2.

[0060] To resume, the Pt-containing materials are also not suitable for SO_x trap.

Table 2: SO_X trap properties of Pt-containing different oxides.

Sample	S(BET), m^2/g	SO_X Loading, mg/g after 1h of sulfation		Desorbed 500°C N_2 0.5h, %	Desorbed in N_2 at T:			Reduced in H_2/Ar at T:			Sulfation light-off T (SLOT), °C
		200°C	500°C		10%	50%	90%	10%	50%	90%	
Cu-PtZrSiO$_2$	373	1.75	22	22.5	540	610	690	215	245	340	375
Pt-TiO$_2$ 600°C	26	15.6	15.9	NA	572	718	NA	277	356	499	
Pt-Al:Ti 1:3 800°C	69	12.6	19.4	17.3	552	645	767	284	361	605	270
Pt-Al:Ti 1:8 800°C	47	25	16.2	18.6	553	642	764	278	364	540	200
Fe-tZrSiO$_2$	389	5	13.3	13.6	550	655	>700	315	365	NA	220
Pt-Al:Ti 1:1 800°C	92	31.5	27.3	11.8	563	667	793	299	378	565	230
Pt-Al:Ti 3:1 800°C	129	41	32.8	11.6	548	655	>800	328	414	551	225
Pt-CeO$_2$	106	14.3	30	1.4	635	690	>700	80	455	520	200
Pt-ZrO$_2$	63	13.2	18	6.6	590	>700	>>70 0	325	462	595	200
Pt-CeZr 1:1	91	51	71	4.6	580	670	>700	405	483	530	200
Pt-CePr 1:1	93	1.25	79	0	>700	>>700	>>>7 00	425	490	546	390
Pt-Al$_2$O$_3$ 800°C	144	22.7	38.2	3.9	>607	764	>800	432	500	674	380
Mn-PtZrSiO$_2$	402	9.3	34	3.1	627	>700	>>70 0	370	517	587	200
Pt-Pr$_6$O$_{11}$	39	19.6	59	NA	>700	>>700	>>>7 00	NA	615	NA	500
Pt-Cordierite	0.5	0.36	1	NA	NA	NA	NA	NA	NA	NA	NA
Pt-TiO$_2$800°C	1	0.19	2.2	0	596	690	798	NA	NA	NA	280

NA- data non-available

Transition metal oxides unsupported

[0061] The adsorption capacity of transition metal oxides (Cu, Zn, Cr, Mn, Co, Ni, Fe) and Ag was quite low, and for the best sample of CuO did not exceed 11 mg/g at 500°C due to the low surface area. Obviously, the supported transition metals oxides will be more preferable. Among the oxides studied, only on copper oxide and silver the temperature of SO_x desorption under reducing conditions was low, namely the temperature of 50% release was 410°C for CuO, and 420°C for Ag, while for iron oxide was near 500°C. The temperature of 50% release was too high, exceeding 550°C for other transition oxides studied, in the range of 565-610°C. Based on these results, we focused basically on Cu-containing systems, taking into account also that the TPR-MS run revealed the formation of only SO_2 under reduction of sulfated CuO.

Non-Pt supported materials and supports

[0062] A summary of the most important properties of oxide systems, including supported transition metals are given in Table 3, the materials with low SO_x capacity are not included.

[0063] Among the SO_x-storage material candidates, the copper containing materials have revealed the best properties, especially Cu-SiO_2 and Cu-Zr-SiO_2. Among other systems studied, there was no material with satisfactory properties. Fe and Ag containing systems had lower adsorption capacity and higher H_2S fraction release, especially Fe, under reductive conditions. Transition metals supported on zeolites, had good releasing properties and good adsorption properties at low temperature of 200°C, but low adsorption capacity, in addition these systems were not stable under operating conditions with irreversible deactivation. Mn, Co, Pr containing systems had the good properties in SO_x removal even at 200°C and high adsorption capacity, but formed too stable sulfates. These systems can be however applied for irreversible SO_x trap, as will be discussed below. Ti and Zr oxides had a low adsorption capacity and high fraction of H_2S, while Y and Ce oxides required the high temperature for regeneration of sulfates collected.

Table 3: SO_X trap properties of non-Pt supported materials.

Sample	S(BET)	SO_X Loading, mg/g after 1h of sulfation:		Desorbed 500°C N_2	Desorbed in N_2 at T:			Reduced in H_2/Ar at T			Sulfation Light-off T
	m^2/g	200°C	500°C	0.5h, %	10%	50%	90%	10%	50%	90%	(SLOT), °C
$Cu_{0.03}$-$ZrSiO_2$(0.97)	374	1.7	13.5	14.8	545	620	700	235	265	330	370
$Cu_{0.03}$-SiO_2(0.97)	444	0.8	12	11.9	550	615	685	241	267	314	380
$Cu_{0.25}$-$ZrSiO_2$(0.75)	294	3.3	104	NA	563	645	>700	242	275	327	355
$Cu_{0.1}$-SiO_2(0.9)	368	0.5	62	NA	572	625	670	235	280	337	350
$Cu_{0.25}SiO_2$(0.75)	235	1.1	97	NA	570	633	NA	260	282	302	360
$Cu_{0.5}La_{0.5}$	6	2.9	13	NA	568	>700	NA	250	297	635	330
$Cu_{0.5}$-Ti-Al(8:1)	131	1.9	138	NA	612	700	>700	277	323	378	360
$Cu_{0.15}Y_{0.85}$	76	1.3	97	NA	NA	NA	NA	296	328	622	405
$Cu_{0.5}Y_{0.5}$	52	2.2	69	NA	580	678	>700	295	330	635	385
$Cu_{0.5}Ce_{0.5}$	12	0.6	33	NA	655	700	>700	300	335	637	390
Cu-ZSM_5	423	3	5.5	5.1	540	660	>700	280	340	465	260
$Cu_{0.25}$-Al_2O_3(0.75)	110	5.5	78	NA	607	>700	NA	317	340	387	380
$Cu_{0.5}Mg_{0.5}$	29	4.1	36	NA	540	>700	NA	312	342	606	397
$Cu_{0.15}Zr_{0.85}$	37	4.4	40	6	80	616	680	320	346	380	370
$Cu_{0.5}In_{0.5}$	42	0.2	89	NA	555	605	>700	305	353	412	390
$Cu_{0.5}Zr_{0.5}$	28	6.2	69	NA	572	600	653	342	365	407	392
Mg-SiO_2	440	0.95	0.5	0	590	690	>700	275	390	570	200
Fe-$ZrSiO_2$	378	1.3	3.3	5.6	670	>700	>700	NA	400	NA	250
CuO	11	0.1	14	NA	597	650	>700	368	411	509	425
Fe-ZSM_{5-50}	~400		7.9	13.6	550	638	>700	335	418	660	200
Fe-ZSM_{5-30}	~400	6.6	15.5	4.4	615	>700	>700	380	430	480	200
10%Zr-SiO_2	400	0.32	1	9	535	635	>700	290	470	510	390

Table continued

Sample	S(BET)	SO_X Loading, mg/g after 1h of sulfation:		Desorbed 500°C N_2	Desorbed in N_2 at T:			Reduced in H_2/Ar at T			Sulfation light-off T
	m²/g	200°C	500°C	0.5h, %	10%	50%	90%	10%	50%	90%	(SLOT), °C
SiO_2	387	0	2.5	NA	585	670	>700	315	490	670	NA
Al:Ti 1:8 800°C	47	2.4	2.2	2	594	683	767	453	500	569	430
Al:Ti 3:1 800°C	129	4.6	2.3	0	670	782	>800	474	515	726	510
Al:Ti 1:3 800°C	69	3.6	2.2	0	692	763	~800	486	517	544	500
Cu,Mg-ZSM_5	360	7	16	3.4	650	>700	>700	395	535	670	260
$Cu_{0.5}Zn_{0.5}$	12	0.2	70	NA	555	600	690	420	538	585	404
$Ag_{0.15}Ce_{0.85}$	36	2.7	66	0	680	>700	>>70 0	378	540	614	390
$Cu_{0.15}Ce_{0.85}$	71	1.4	105	0.5	670	695	>700	480	540	570	440
Al:Ti 1:1 800°C	92	5.0	1.7	0	702	791	>800	510	542	642	510
CeZr 1:1	129	12	36	1.5	620	675	>700	500	550	570	330
ZrO_2 TiO_2 600°C	63	6.3	8.8	1.6	635	>700	NA	520	555	600	440
	26	2.3	3	1	615	NA	NA	500	556	574	NA
Ce-SiO_2	408	0.4	4	1.5	615	674	>700	470	574	612	NA
Al_2O_3 800°C	144	12.7	9.5	2.1	700	>800	>800	517	582	715	660
CeO_2	106	3.1	30	1.2	670	695	>700	580	590	615	440
Y_2O_3	112	3.1	48	NA	>700	NA	NA	575	605	645	420
$Ag_{0.3}La_{0.7}MnO_x$	58	2.6	18	NA	690	>700	NA	413	615	651	370
$Co_{0.15}Ce_{0.85}$	96	0.4	11	NA	>700	NA	NA	580	619	640	385
ZrPr 1:1	90	24.4	31	1.35	>700	>>700	>>>70 0	595	660	NA	200
Pr_6O_{11}	39	15.2	60	0	583	>700	>>70 0	583	675	>700	500
CePr 1:1	93	3.6	39	1.24	>700	>>700	>>>70 0	643	677	688	500
$Mn_{0.15}Y_{0.85}$	134	4.3	202	NA	>700	NA	NA	640	692	772	413

NA-non-available

Copper-based systems (invention)

[0064] . The most important properties of copper-based systems are summarized in Fig.3, see also Table 3. Temperature of 50% sulfates reduction release under TPR conditions was minimal for Cu-$ZrSiO_2$ and Cu-SiO_2, low temperature release was found also for Cu-zirconia, Cu-alumina, Cu-titania-alumina, CuZSM5, Cu-In_2O_3 and for copper systems with yttria, lanthania and ceria with high copper concentration. The latter systems had however at least two desorption peaks, one is obviously connected with CuO or Cu-enriched phase released at low temperature, and the high temperature peak connected with yttria, lanthania or ceria, as comparison with those pure oxides has shown. Therefore these systems are not suitable for SO_x trap, because it is not possible to regenerate it completely at temperatures below 500°C. Cu-Zn and Cu-Ce mixed oxides have too high temperature of desulfation under reducing conditions. Data show that Cu on SiO_2 and Zr-SiO_2 has the lowest temperature of the complete reductive regeneration; practically complete regeneration occurred at temperatures below 330°C, see Fig.4. The addition of Zr allows increasing of low-temperature sulfation and slightly the adsorption capacity. SO_2 was the major product of sulfur reduction. For Cu-titania samples, one can see the single peak of SO_2 release, but the complete regeneration requires higher temperature near 400°C, see Fig.5. For copper-alumina there was 3 peaks of SO_2 desorption with practically complete removal of SO_2 near 450°C, see Fig.6. Copper-zirconia system also allows to regenerate all sulfates accumulated at 435°C. For copper-india, there were 2 peaks with complete desorption of SO_2 at 450°C.

[0065] Noticeably, these systems have lower temperature release of SO_2 than pure CuO under reducing conditions, and support oxides itself, see Table 3. It shows that the combination of copper with those oxides leads to less stable sulfates and beneficial for SO_x trap properties. Also, the significant increase of adsorption capacity was found in comparison with pure CuO probably due to the higher surface area of such mixed oxides combinations. The systems release SO_2 as dominant product under reducing conditions in contrast to Pt-containing systems. The important advantage of these systems is also low cost, except Cu-In_2O_3, and convenient method of preparation by impregnating commercial supports with copper nitrate for Cu-silica and Cu-alumina.

[0066] The only disadvantage of Cu-based systems is lower activity of SO_2 oxidation to SO_3 and accordingly lower SO_x removal at low temperatures of 200°C in comparison with Pt-containing materials, but considering SO_x trap installation downstream of Pt-containing Diesel oxidation catalyst or Catalyzed Soot Filter, the Cu-based materials can cope with SO_x removal at low temperatures.

[0067] Summarising, Cu-containing adsorbents, especially Cu/SiO_2, Cu/$ZrSiO_2$, and also Cu/Al_2O_3, Cu/TiO_2-Al_2O_3, Cu/ZrO_2, Cu/In_2O_3 are the most promising for applications as an reversible SO_x trap material.

Irreversible SO_x traps

[0068] The term "irreversible trap" means that a trap cannot be regenerated at typical temperature range of NO_x trap operation at 300-450°C. So the desulfation (regeneration) of this trap requires the separate mode of operation, e.g. it will be necessary to raise temperature under rich conditions. Such traps are less attractive than reversible traps, nevertheless such traps would get an advantage before current NO_x trap technology, because it will prevent sulfur poisoning of NO_x trap between desulfation events. As the results, the NO_x trap performance will not be deteriorated, while desulfation can be done at the same mode as current desulfation strategy, by rising temperature to 600-650°C under rich conditions for 10-20 minutes. Such traps are also valuable for SO_x removal from stationary engines, industry and power plants, when the traps may be desulfated even at lean conditions. From this point of view, the candidate material for irreversible trap must have a high SO_x storage capacity at 200-500°C. From materials tested, see Table 3, Pr_6O_{11} and mixed PrZr oxides show the good properties, comparable at low temperature of 200°C even with Pt-containing materials, see Table 2. Taking into account the disadvantages of Pt catalysts, namely high cost, irreversible poisoning by components of exhaust gases, especially in industry and power plants, H_2S release under reducing conditions, see Figure 2, these praseodymia-based systems have a potential for such applications. Mn-Y mixed oxide has revealed a highest adsorption capacity, but it was less active in desulfation at low temperature and required higher temperature of desulfation, see Table 3.

[0069] Platinum group metal- free (PGM-free) regenerable catalyst composition suitable for entrapping SO_x having the general structure

Cu/ A oxide

whereby
A oxide represents SiO_2, Zr-SiO_2, Al_2O_3, TiO_2-Al_2O_3, ZrO_2 and In_2O_3 and mixtures thereof.

[0070] Use of a catalyst composition for adsorbing SO_x as metal sulfate at a temperature range of 200 °C to 500 °C

under lean (oxidative) conditions.

[0071] Use of a catalyst composition for desorbing metal sulfates at a temperature range of 250 °C to 450 °C under rich (reducing) conditions.

[0072] Platinum group metal free (PGM-free) regenerable catalyst composition suitable for entrapping SO_x containing praseodymia, zirconia-praseodymia and mixed manganese-yttria and mixtures thereof.

[0073] Use of a catalyst composition for adsorbing SO_X as metal sulfate at a temperature in the range of 200 °C to 500 °C under lean (oxidative) conditions.

[0074] Use of a catalyst composition for desorbing metal sulfates at a temperature in the range of 600 °C to 650 °C under rich (reducing) conditions.

[0075] Diesel oxidation catalyst (DOC) comprising a catalyst composition.

[0076] Diesel oxidation catalyst (DOC) comprising a catalyst composition.

[0077] Diesel oxidation catalyst (DOC), whereby the catalyst composition according to claim 1 is installed upstream of an NO_X trap, in particular downstream of said DOC.

[0078] Diesel oxidation catalyst (DOC), whereby the catalyst composition according to claim 1 is installed upstream of an NO_x trap, in particular downstream of said DOC.

[0079] Catalyzed soot filter (CSF) comprising a catalyst composition.

[0080] Catalyzed soot filter (CSF) comprising a catalyst composition.

[0081] Catalyzed soot filter (CSF), whereby the catalyst composition according to claim 1 is installed upstream of an NO_x trap, in particular downstream of said CSF.

[0082] Catalyzed soot filter (CSF), whereby the catalyst composition according to claim 1 is installed upstream of an NO_x trap, in particular downstream of said CSF.

Claims

1. Process of elimination of exhaust gas emissions, including the step of

   a) entrapping SO_x on a platinum group metal free (PGM-free) regenerable catalyst composition containing praseodymia, zirconia-praseodymia and mixed manganese-yttria and/or mixtures thereof by adsorbing SO_x as metal sulfate at a temperature in the range of 200 °C to 500 °C under lean (oxidative) conditions and
   b) disulfation (regeneration) by desorbing metal sulfates at a temperature in the range of 600 °C to 650 °C under rich (reducing) conditions.

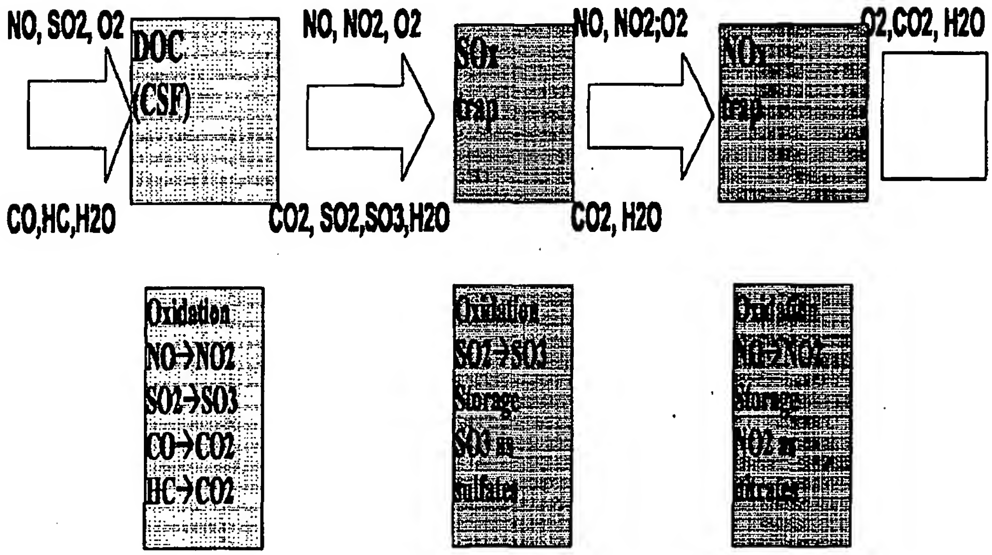
2. The process according to claim 1, **characterized in that** the catalyst composition is comprised in a diesel oxidation catalyst (DOC).

3. The process according to claim 2, **characterized in that** the catalyst composition is installed upstream of a NO_x trap.

4. The process according to claim 1, **characterized in that** the catalyst composition is comprised in a catalyzed soot filter (CSF).

5. The process of claim 4, whereby the catalyst composition is installed upstream of a NO_X trap.

Fig.1. LEAN CONDITIONS



RICH CONDITIONS

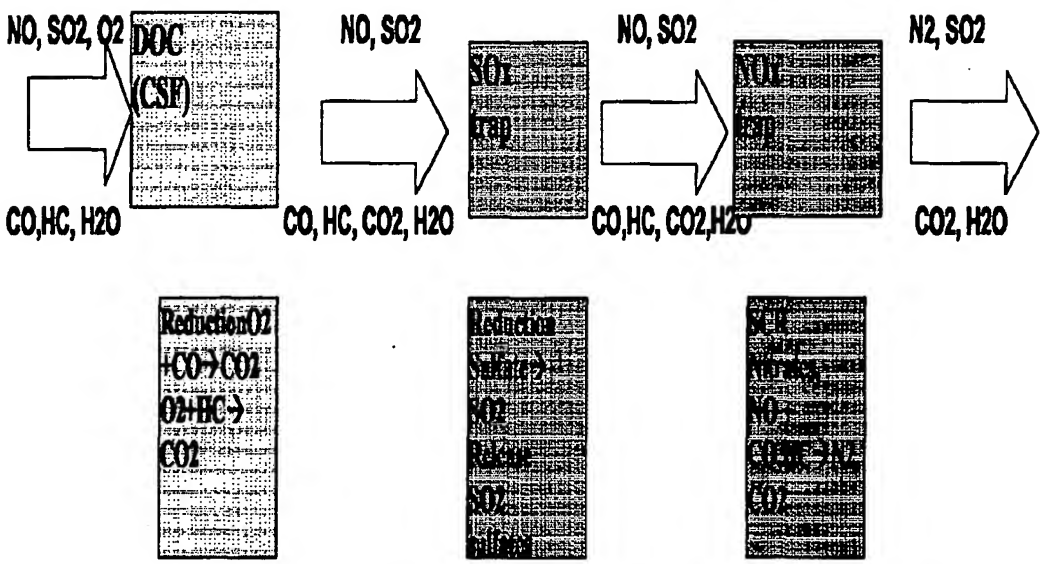


Fig.2.TPR-MS of sulfated Pt-CeZr1:1(#50)

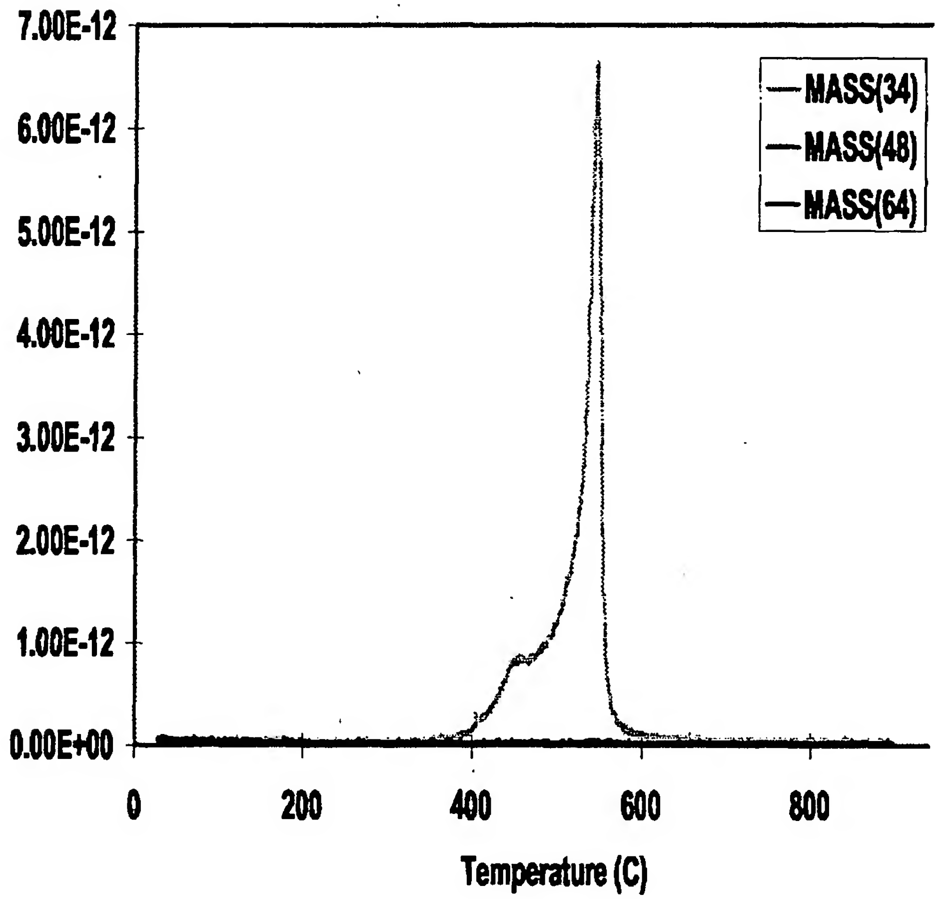


Fig.3. SOx properties of Cu-containing materials

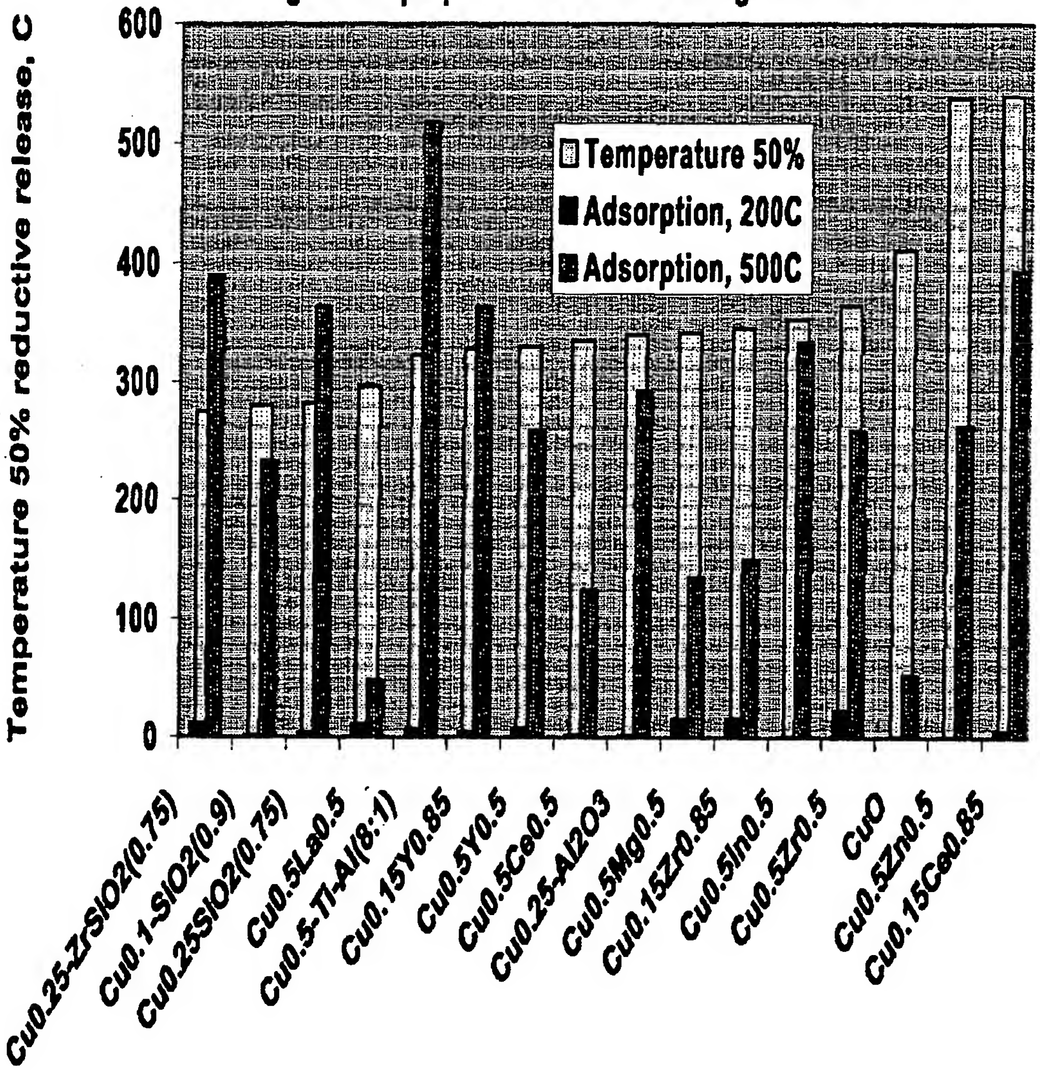


Fig.4. TPR-MS of Cu0.25SiO2(0.75), sulfated at 500C (ID030)

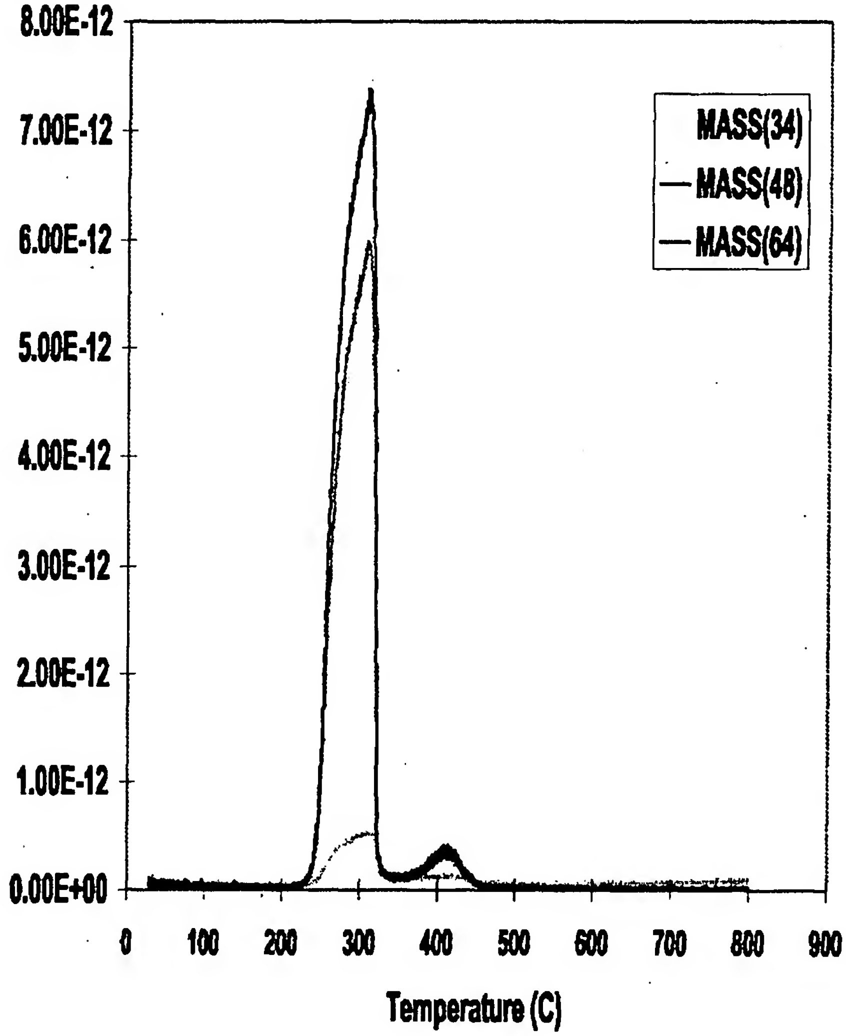


Fig.5. TPR-MS of Cu-Ti-Al (8:1), sulfated at 500C (ID031)

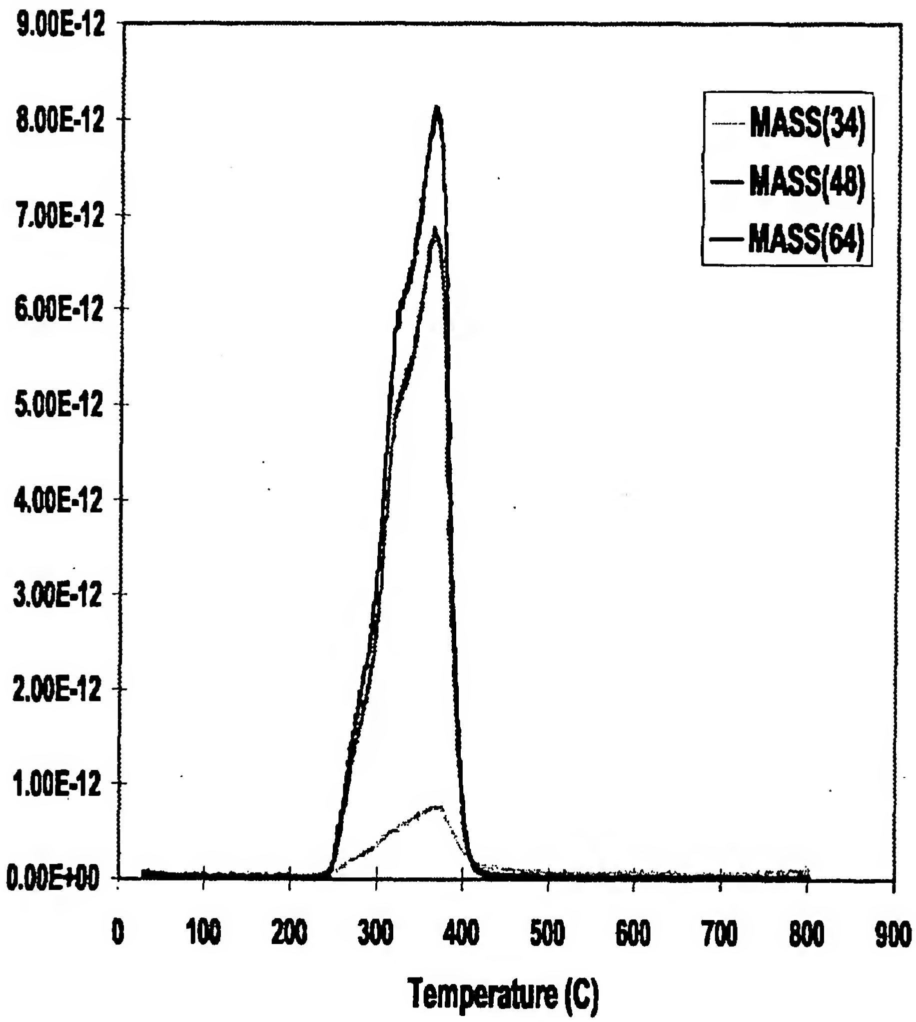


Fig.6. TPR-MS of Cu0.25-gamma Al2O3(0.75), sulfated at 500C (ID032)